Reprinted from “Bulletin of Marine Science” Volume 33, 1983, pp. 935-940, Parker et al.: Estimated amount of reef habitat on a portion of the U. S. South Atlantic and Gulf of Mexico Continental Shelf. With permission from Rosenstiel School of Marine and Atmospheric Science of the University of Miami.

SHORT PAPER

BULLETIN OF MARINE SCIENCE, 33(4): 935–940. 1983

ESTIMATED AMOUNT OF REEF HABITAT ON A PORTION OF THE U.S. SOUTH ATLANTIC AND GULF OF MEXICO CONTINENTAL SHELF

R. O. Parker, Jr., David R. Colby and T. D. Willis

Reef fish exist on the U.S. Continental Shelf from Cape Hatteras to Key West and throughout the Gulf of Mexico. Reef fish communities in this area include large stocks of seabass, snappers, groupers, porgies and grunts. Catch and effort statistics, the usual data base for estimating potential yield, are not available for most of these stocks. To provide an early estimate of potential yield and one independent from catch-effort data, we plan to use a method that predicts maximum sustainable yield as a function of stock biomass (Alverson and Pereyra, 1969; Gulland, 1971). Biomass estimates sufficiently accurate for initial management plans can be obtained by multiplying the amount of reef habitat by the mean fish biomass per unit of reef area. A major problem is that no published estimates exist either of the amount of reef habitat or of mean fish biomass.

Miller and Richards (1979) reported that live bottom reef habitat is scattered throughout the Continental Shelf off the South Atlantic United States out to the 200-m depth contour but they did not estimate the amount. In this paper we estimate the amount of reef area on the Shelf between the 27- to 101-m isobaths, Cape Hatteras to Cape Canaveral, and between the 18- and 91-m isobaths, Key West to the Mexican border. In the future we hope to estimate the mean fish biomass per unit of reef area, and hence be able to estimate stock biomass and potential yield.

Materials and Methods

The amount of reef habitat (rock, coral and sponge) on the Continental Shelf of the South Atlantic and Gulf coasts of the United States was estimated from observations made with submersible television. The survey area was divided into four strata. At randomly selected points, or stations, within each stratum the bottom was classified either as reef or non-reef. If reef, was the relief less than 1 m or greater than 1 m? If non-reef, was it vegetated or bare sand, sand/shell or mud? From the proportion of reef to non-reef in the samples and from the known area of each stratum, the amount of reef was estimated. Strata were delineated on National Oceanic and Atmospheric Administration (NOAA) charts. Prominent geographical features marked the end boundaries of each stratum (Table 1), and inshore-offshore boundaries followed specific depth contours. The inshore boundary was limited to the yearly existence of several species of commonly caught reef fish. It was closer to the shoreline in the Gulf than in the Atlantic because warmer waters in the Gulf allow reef fish to exist farther inshore throughout the year. Offshore boundaries were determined by the length of the television cable used for the surveys. The survey of one stratum, Cape Hatteras to Cape Canaveral, was completed ahead of schedule. For analysis, we divided it into two strata and sampled additional stations between Cape Hatteras and Cape Fear.

The sampling frame for the survey consisted of the set of all points specified by latitude and longitude (in degrees, minutes, and seconds) that fell within the boundaries of the strata. A program was written in SAS (Barr et al., 1976) to draw a specified number of these points, or stations, at random from each stratum. Existing estimates of the percentage of reef habitat in each stratum were used to calculate the number of sample stations required to estimate the true percentage of reef habitat in each stratum

Table 1. Coordinates marking the boundary of each stratum in degrees and minutes

	Terminal Points			
	Inshore		Offshore	
	Latitude (N)	Longitude (W)	Latitude (N)	Longitude (W)
Cape Hatteras	35 09	75 18	35 05	75 13
Cape Fear	33 21	78 01	33 02	77 54
Cape Canaveral	28 27	80 21	28 27	80 00
Key West	25 00	81 35	24 33	82 00
Pensacola	30 21	86 46	29 49	87 11
Pass Cavallo	28 16	96 30	27 45	96 04
Rio Grande	26 00	96 56	26 00	96 20

within ±5% (Cochran, 1963). These estimates were 10% for the Continental Shelf (Hedgpeth, 1957; Struhsaker, 1969), 3.7% from Cape Hatteras to Cape Canaveral (BLM data[1]), 3% from Cape Hatteras to Cape Canaveral (Huntsman[2]), 3–5% off the Georgia coast (Henry[3]), and 10–50% for the Gulf of Mexico (Benigno[4]). The randomly selected stations were converted from latitude and longitude to Loran C coordinates for navigational purposes.

Visual determination of bottom type was made with a closed-circuit underwater television (CCUTV) system. The CCUTV system consisted of a black and white television camera and a 1,000-watt mercury vapor light housed in a protective metal frame. The system was lowered from the FRS OREGON II (a 52 m long NOAA research ship) to the substrate, then raised for video monitoring and taping while the ship and system were drifting.

An observer recorded the type of habitat seen during the initial view of a meter quadrate of the sea floor. Although the substrate was classified during the initial glimpse of the sea floor, up to 15 min were spent examining the bottom at some stations. These supplemental observations supported our initial classification of habitat type in each case.

The South Atlantic Bight, Cape Hatteras to Cape Canaveral, was surveyed 18 March through 12 April 1978. The U.S. Gulf of Mexico was surveyed 16 November through 18 December 1978 and 15 June through 24 June 1979.

Total reef area within each stratum was estimated by multiplying the percentage of stations classified as reef by the total area (Table 2), determined by planimetric measurement of NOAA charts 11009 and 411. Total reef area for all strata was determined by summing the estimates of each stratum. Confidence limits for the proportion of reef habitat in a stratum were based on interpolation of tabled values presented by Rohlf and Sokal (1969), according to the methods of Mainland et al. (1956). Estimates of proportions, standard errors, and confidence limits for the entire surveyed area were calculated by using formulae presented by Cochran (1963) for stratified random sampling of attributes.

RESULTS AND DISCUSSION

Reef Habitat

Reef habitat was estimated to be 57,159 km^2, or 22.8% of the total area surveyed (Table 3). Only 1.7%, or 4,143 km^2, had 1 m or more relief. Sand or sand/shell constituted 48.8% of the stations, mud 24.8% and vegetation 3.6% (Table 4). As expected, considerable variability in amount of reef habitat existed from one location to another (Fig. 1). In all areas the distribution of rock, coral and sponge was patchy. By far the largest amount of estimated reef habitat, 44,936 km^2, was between Key West and Pensacola, Florida. Reef habitat was scattered from Key

[1] Bureau of Land Management visual graphics for proposed Outer Continental Shelf Lease Sale No. 43.

[2] G. R. Huntsman, NOAA, National Marine Fisheries Service, Southeast Fisheries Center, Beaufort Laboratory, Beaufort, NC 28516-9722.

[3] V. J. Henry, Skidaway Institute of Oceanography, Skidaway Island, Savannah, GA 31406.

[4] J. Benigno, NOAA, National Marine Fisheries Service, Southeast Fisheries Center, Pascagoula Laboratory, Pascagoula, MS 39567-0112.

Table 2. Strata surveyed and proportions of stations that were reef habitat

Stratum	Sample Size	Area (km²)	Anticipated* Proportion	Observed Proportion
Cape Hatteras to Cape Fear (27–101 m)	71	14,486	0.10	0.14
Cape Fear to Cape Canaveral (27–101 m)	57	24,826	0.10	0.30
Key West to Pensacola (18–91 m)	382	117,573	0.50	0.38
Pensacola to Pass Cavallo (18–91 m)	122	78,382	0.10	0.03
Pass Cavallo to Rio Grande (18–91 m)	228	15,816	0.20	0.01

* Based on estimates in Materials and Methods section.

West to Apalachicola, but only in the Florida Middle Grounds, a heavily fished area (Fig. 1), did it exceed 1 m of relief. Vegetation, predominantly algae, occurred at shallower stations, and there were some areas of seagrass north of Tampa. Stations between Apalachicola and Pensacola were primarily sand/shell. Reef habitat was found at 24% of the stations between Cape Hatteras and Cape Canaveral. This compares favorably with data by Miller and Richards (1979), who found reef fish in samples at 18.9% of 5,300 trawl stations made during cruises in the area by the R/V SILVER BAY. The similarity of these results indicates that trawling records also can be used to estimate the amount of reef habitat.

Because of gear and time restraints and already available knowledge (unpublished), areas between 101 m and 183 m in the South Atlantic, 18 m and 183 m from Cape Canaveral to Key West, and 91 m and 183 m in the Gulf of Mexico were not surveyed. Although these areas are small relative to those surveyed, they contain prime reef fish habitat and probably contribute significantly to the total amount.

Estimates of potential yield of reef fish, independent from those obtained from catch-effort data, will be made when our studies of reef fish biomass per unit area of habitat have been completed. The small amount of reef fish habitat in U.S. waters, as indicated by this study, and the fact that many economically important reef fish take several years to reach maturity and reproduce, strongly suggest that these species cannot withstand heavy fishing (Huntsman and Manooch, 1978; 1979; Manooch and Haimovici, 1978; Nelson and Manooch, 1982).

Table 3. Estimates of percentages and area of reef habitat by stratum and for all strata combined (95% confidence limits are in parentheses)

Stratum	Percentage		Area (km²)	
	All Reef Habitat	>1 m*	All Reef Habitat	>1 m*
Cape Hatteras–Cape Fear	14.1 (7.1–24.3)	1.4 (0.1–7.5)	2,040 (1,027–3,500)	204 (12–1,091)
Cape Fear–Cape Canaveral	29.8 (18.6–43.3)	7.0 (2.0–17.0)	7,403 (4,608–10,745)	1,743 (504–4,208)
Key West–Pensacola	38.2 (33.4–43.2)	0.8 (0.2–2.2)	44,946 (39,305–50,768)	941 (259–2,622)
Pensacola–Pass Cavallo	3.3 (0.9–8.2)	1.6 (0.2–5.8)	2,571 (737–6,388)	1,285 (188–4,515)
Pass Cavallo–Rio Grande	1.3 (0.3–3.8)	0.0 (0.0–1.6)	209 (51–596)	0 (0–255)
Estimates for all strata combined	22.8 (19.9–25.6)	1.7 (0.6–2.7)	57,159 (49,979–64,340)	4,173 (1,461–6,885)

* Refers to area of relief >1 m.

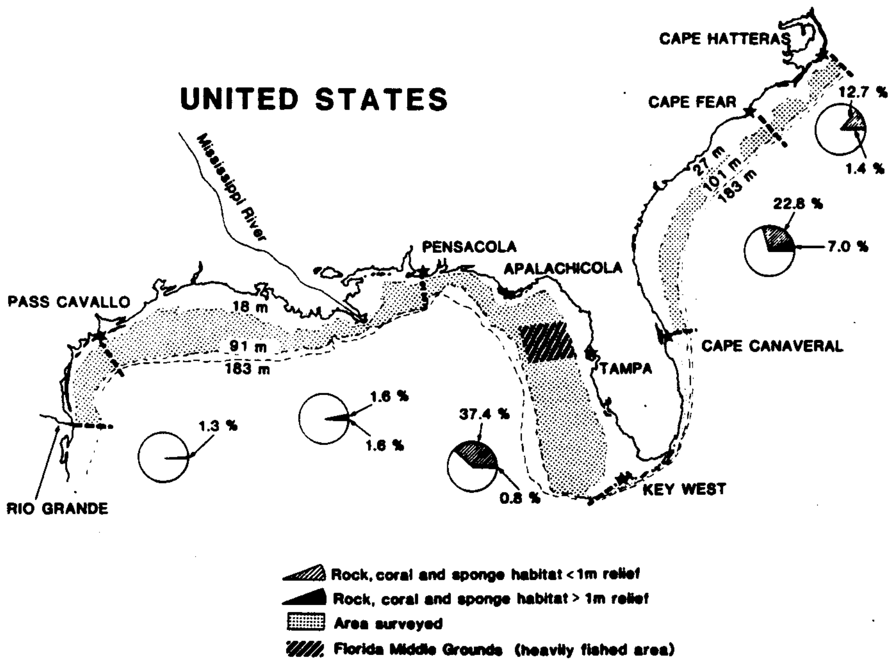

Figure 1. Survey area (see Table 1 for location of coordinates separating strata) and relative amount of reef habitat (shown in pie diagrams).

Survey Techniques Problems

The type of habitat recorded was the type we observed during our initial view of the sea floor. Although the survey design called for an observation of 1 m^2 at each station, this did not always occur. Varying turbidity, currents, boat drift, and seas made it impossible to determine the extent or size of the viewing area. At some stations, only a glimpse of the bottom could be obtained, at others, long transects were possible. Regardless of CCUTV bottom time, habitat remained generally the same throughout the drift.

Hypothetical Allocation of Survey Effort

Survey effort was allocated among strata so that estimated proportions in each stratum would have 95% confidence intervals of ±5%. To evaluate efficiency of

Table 4. Percentage of stations by stratum classified in habitat categories

Stratum	Percentage			
	Sand/Shell	Mud	Vegetation	Reef
Cape Hatteras–Cape Fear	74.6	11.3		14.0
Cape Fear–Cape Canaveral	57.9		12.3	30.0
Key West–Pensacola	57.1	4.4	0.3	38.0
Pensacola–Pass Cavallo	27.0	68.9	0.8	3.0
Pass Cavallo–Rio Grande	57.9	39.5	1.3	1.0
Weighted mean	48.8	24.8	3.6	22.8

Table 5. Actual sample sizes for different strata and alternative allocations of sampling effort

Stratum	Actual Sample Size	Estimated Sample Size*	Proportional Allocation†	Optimum Allocation‡
Cape Hatteras to Cape Fear	71	139	135	101
Cape Fear to Cape Canaveral	57			
Key West to Pensacola	382	386	403	503
Pensacola to Pass Cavallo	122	139	268	201
Pass Cavallo to Rio Grande	228	247	54	55
	860	911	860	860

* $n_h = (1.96)\hat{p}_h\hat{q}_h/(0.05)^2$.
† $n_h = nN_h/\Sigma N_h$.
‡ $n_h = n(N_h)(\hat{p}_h\hat{q}_h)^{0.5}/\Sigma[N_h(\hat{p}_h\hat{q}_h)^{0.5}]$.

the sampling design, we compared our results with hypothetical results that would have been obtained if sampling effort had been allotted by two other ways.

In the first of these, proportional allocation, sample size of each stratum is made proportional to the size of that stratum (Cochran, 1963). This approach is recommended when variance and costs for strata are about equal. Because individual stratum estimates are self-weighting, estimates for the entire population can be calculated directly. Proportional allocation would have assigned considerably more effort to the region between Pensacola and Pass Cavallo than we assigned and much less to the region from Pass Cavallo to the Rio Grande (Table 5). Under the proportional allocation technique the standard error of the estimate would have been reduced from 1.43% to 1.32%.

In the second method, optimum allocation, both size of the stratum and the variance that is expected within each stratum are incorporated in the design (Cochran, 1963). If costs of sampling a unit differ among strata, the information can be incorporated in the allocation process, but for our comparison, we considered costs per sample unit to be the same in all strata. Optimum allocation would have assigned about 59% of the stations to the Key West to Pensacola stratum; again, effort in the Pass Cavallo to Rio Grande stratum would have been only about one-fourth the effort of that actually applied. The standard error would have been reduced to 1.28%.

It is clear that the gains in precision from either of the two alternative sample allocation procedures would have been slight. In addition, either of those approaches would have led to greater disparity in the precision of estimates for individual strata.

Literature Cited

Alverson, D. L. and W. T. Pereyra. 1969. Demersal fish explorations in the northeastern Pacific Ocean—an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Board Can. 26: 1985–2001.

Barr, A. J., J. H. Goodnight, J. P. Sall and J. T. Helwig. 1976. A user's guide to SAS 76. SAS Institute, Raleigh, North Carolina. 329 pp.

Cochran, W. G. 1963. Sampling techniques. 2nd ed. Wiley, New York. 413 pp.

Gulland, J. A. 1971. Science and fishery management. J. Cons. Cons. Int. Explor. Mer 33: 471–477.

Hedgpeth, J. W. 1957. Treatise on marine ecology and paleoecology. Vol. 1. Geol. Soc. Am. Mem. 67. 1,296 pp.

Huntsman, G. R. and C. S. Manooch, III. 1978. Coastal pelagic and reef fishes in the South Atlantic Bight. Pages 97–106 *in* H. Clepper, ed. Marine recreational fisheries, 3. Sport Fishing Institute, Washington, D.C.

——— and ———. 1979. Minimum size limits for reef fishes. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 32: 509–513.

Mainland, D., L. Herrera and M. I. Sutcliffe. 1956. Statistical tables for use with binomial samples: contingency tests, confidence limits, and sample size estimates. Department of Medical Statistics, New York University College of Medicine, New York. 83 pp.
Manooch, C. S., III and M. Haimovici. 1978. Age and growth of the gag, *Mycteroperca microlepis*, and size-age composition of the recreational catch off the southeastern United States. Trans. Am. Fish. Soc. 107: 234–240.
Miller, G. C. and W. J. Richards. 1979. Reef fish habitat, faunal assemblages, and factors determining distributions in the South Atlantic Bight. Proc. Gulf Caribb. Fish. Inst. 32: 114–130.
Nelson, R. S. and C. S. Manooch, III. 1982. Growth and mortality aspects of natural populations of red snapper, *Lutjanus campechanus*, from the western central Atlantic and northern Gulf of Mexico. Trans. Am. Fish. Soc. 111: 465–475.
Rohlf, F. J. and R. R. Sokal. 1969. Statistical tables. Freeman, San Francisco. 253 pp.
Struhsaker, P. 1969. Demersal fish resources: composition, distribution, and commercial potential of the continental shelf stocks off southeastern United States. Fish. Ind. Res. 4: 261–300.

DATE ACCEPTED: December 20, 1982.

ADDRESS: *National Marine Fisheries Service, NOAA, Southeast Fisheries Center, Beaufort Laboratory, Beaufort, North Carolina 28516.*